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Measurement of Electroweak Vector Boson Pair Production in pp Collision with the CMS Detector at LHC

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ABSTRACT

We present an overview of measurements of electroweak vector boson pair production and anomalous Triple Gauge Couplings (aTGC), with semileptonic and fully leptonic final states. The data analyzed were taken at center of mass energy of 7 & 8 TeV by the CMS detector at the Large Hadron Collider. The cross-section measurements are important because they are test of the Standard Model predictions, while these processes serve as background for Higgs searches and various other processes.

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1 Introduction

Electroweak Vector Boson pair production provides an important test of the Standard Model (SM) of particle physics. These processes are backgrounds to important searches such as Higgs Boson, Supersymmetric particles etc. and their understanding are necessary for exploring VV scattering. Further, any deviation in the production cross-sections or in kinematics from the SM predictions can provide a possible hint to new physics. The experimental results reviewed here use pp collision at the Large Hadron Collider (LHC) at a center-of-mass energy $\sqrt{s} = 7$ and 8 TeV, with an integrated luminosity up to about 19.6 fb^{-1} .

2 Cross Section Measurements

2.1 ZZ in four leptons

The ZZ production cross section has been measured in the following final states, $ZZ \rightarrow \ell\ell'\ell'\ell'$, where $\ell = e, \mu$, and $\ell' = e, \mu$ and τ [1] and $ZZ \rightarrow 2\ell 2\nu$ [2, 3]. For $ZZ \rightarrow \ell\ell'\ell'\ell'$ signal is characterized by four charged leptons. Events are selected to get mutually exclusive set of signal candidates in the $ZZ \rightarrow \ell\ell\ell\ell$, and $ZZ \rightarrow \ell\ell\tau\tau$ channels. Z candidate is formed using a pair of well-identified and isolated leptons of the same flavor and opposite charge with invariant mass consistent with the nominal mass of Z boson. The major background contributions arise from the production of Z and WZ in association with jets and from $t\bar{t}$. In all these cases, a jet or a non-isolated lepton is misidentified as a lepton. We estimate these backgrounds in data-driven way using appropriate control region by relaxing isolation criterion. In $ZZ \rightarrow 2\ell 2\nu$, the signal consists of two Z bosons such that one decays into a pair of opposite-charged leptons (e or μ), and the other to two neutrinos (ν) that escape direct detection [2, 3]. The final state is thus characterized by a pair of opposite-charge, isolated electrons or muons, with invariant mass close to nominal mass of Z boson; no additional leptons, other than the muon or electron pair from the Z decay; and large missing transverse energy (MET). Z boson mass criterion suppresses all backgrounds which do not have real Z boson while lepton veto suppresses WZ background. Given that the ZZ pair is produced in the collision of two hadrons, extra jets may be found in the event. In order to minimize backgrounds coming from top quarks, events are vetoed if a b-tagged jet is found. Furthermore, the MET based variables are used to suppress Drell-Yan (DY) background. Data-driven method is used to estimate DY background using γ +jets control sample. We also use another data-driven method to estimate background events which does not involve Z boson such as WW and top quark production.

2.2 WZ in $3\ell\nu$

The signal signature is characterized by a pair of same-flavor, opposite-charge, isolated leptons with an invariant mass consistent with the Z boson, together with a third isolated lepton and a significant amount of MET associated with the escaping neutrino [4]. Backgrounds are grouped as: non-peaking background such as $t\bar{t}$, QCD multijet and W +jets production; Z +fake lepton background; and Z +prompt lepton background. Z +fake lepton backgrounds are the most important for the $WZ \rightarrow 3\ell\nu$ process; they include fake or non-isolated leptons from jets (including heavy quark jets) or photons. Z +prompt lepton backgrounds originate primarily from the $ZZ \rightarrow 4\ell$ process, where one of the four leptons is lost; it is irreducible but small due to relatively small production cross section. The contributions from other backgrounds are negligibly small.

2.3 WW in $2\ell 2\nu$

The signal is characterized by two opposite charged isolated leptons (electrons or muons) accompanied by significant amount of MET [5, 6]. Background processes in this analysis include W +jets, $W\gamma$, and QCD multijet events where at least one of the jets is misidentified as a lepton, top production ($t\bar{t}$ and tW), DY, and diboson production (WZ and ZZ). Top contribution is suppressed by applying additional jet veto. DY acts as a background in two cases: first, when poorly reconstructed leptons or jets are mismeasured as MET, which is suppressed by requiring *projected* E_T^{miss} above certain threshold. Second, when the Z boson recoils against a jet. In this case the angle in the transverse plane between the dilepton system and the most

energetic jet with transverse energy (E_T) above 15 GeV is required to be smaller than 165 degrees. This selection is applied only in the e^+e^- and $\mu^+\mu^-$ final states. Further DY background in the e^+e^- and $\mu^+\mu^-$ final states is reduced by requiring dilepton mass within 15GeV of the Z mass. Events with dilepton masses below 12 GeV are also rejected to suppress contributions from low-mass resonances. The same requirement is also applied in the $e^\pm\mu^\mp$ final state. Diboson processes, such as WZ and ZZ production, are suppressed by third lepton veto. $W\gamma$ production, in which photon converts, is suppressed by rejecting electrons consistent with a photon conversion. A combination of data-driven method and Monte Carlo (MC) simulation studies are used to estimate background contributions.

2.4 $WW + WZ$ in $\ell\nu jj$

Events are selected with one well-identified and isolated lepton (muon or electron), large MET, and exactly two high- p_T jets[7]. The advantage of reconstructing $WW+WZ$ in semileptonic final state over the purely leptonic process is that the W and Z bosons have large branching ratio to quarks decay than lepton decays. However, this is partially nullified due to presence of huge W +jets background having large cross section. Backgrounds to this process arise from W/Z +jets, QCD multijet, $t\bar{t}$ and single top. Top is suppressed by additional jet veto. To reduce the background from processes that do not contain $W \rightarrow \ell\nu$ decays, transverse mass of the W candidate is required above 30(50) GeV in μ (ℓ) data. To suppress DY and electroweak diboson purely-leptonic decay processes, we use additional lepton veto. QCD multijet background is estimated in a data-driven way from two component fit to data on MET distribution, which determines the corresponding fraction in data. The signal is extracted by an unbinned maximum likelihood fit over dijet mass distribution in the mass range 40-150GeV keeping diboson contribution normalization as free parameter. The normalization of other backgrounds are allowed to vary within Gaussian constraints around their central values. The central values of these backgrounds are taken from next-to-leading or higher order theoretical calculations.

2.5 VZ in $VZ \rightarrow Vb\bar{b}$

The VZ , where $V = W/Z$ production cross-section has been measured in the $VZ \rightarrow Vb\bar{b}$ decay mode with, the subsequent decay mode of V being $Z \rightarrow \nu\bar{\nu}$, $W \rightarrow \ell\nu$ and $Z \rightarrow \ell\ell$ ($\ell = e, \mu$) [8]. The event selection is based on the reconstruction of the vector bosons in their leptonic decay modes and of the Z boson decay into two b-tagged jets. Dominant backgrounds to VZ production originate from V +heavy flavor (HF) jets, V +LF light flavor (LF) jets, $t\bar{t}$, single top, multi-jet QCD and Higgs production. In general b-tagging is used to reduce LF components, additional jet activity veto is used to reduce $t\bar{t}$ and single top events. The cross sections are extracted simultaneously for WZ and ZZ production for the inclusive phase space and in a fiducial region for a V transverse momentum above 100 GeV with the Z bosons produced in the mass region $60 < M_Z < 120$ GeV.

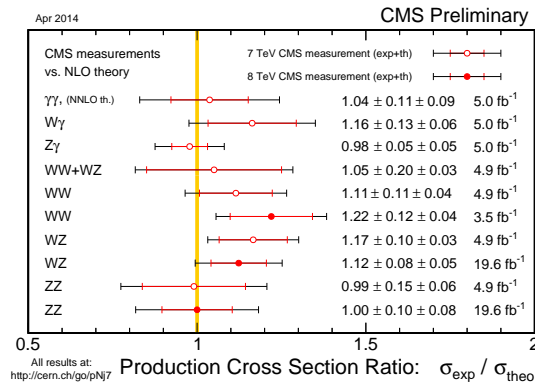


Figure 1: Relative Production cross-section for various Electroweak boson pairs w.r.t. SM

Process	Measured (σ in pb)	Predicted(σ in pb)	Lumi. in fb^{-1}
ZZ in $\ell\ell'\ell'$	$7.7^{+0.5}_{-0.5}$ (stat.) $^{+0.5}_{-0.4}$ (syst.) ± 0.4 (theo.) ± 0.3 (lumi.)	7.7 ± 0.6	19.6 at 8 TeV
ZZ in $2\ell 2\nu$	$6.8^{+0.8}_{-0.8}$ (stat.) $^{+1.8}_{-1.4}$ (syst.) ± 0.3 (lumi.)	$7.92^{+4.7\%}_{-3.0\%}$	19.6 at 8 TeV
WZ in $3\ell\nu$	24.61 ± 0.76 (stat.) ± 1.13 (syst.) ± 1.08 (lumi.)	$21.91^{+1.17}_{-0.88}$	19.6 at 8 TeV
WW in $2\ell 2\nu$	69.9 ± 2.8 (stat.) ± 5.6 (syst.) ± 3.1 (lumi.)	$57.3^{+2.4}_{-1.6}$	3.54 at 8 TeV
$WW + WZ$ in $\ell\nu jj$	68.9 ± 8.7 (stat.) ± 9.7 (syst.) ± 1.5 (lumi.)	65.6 ± 2.2	5.0 at 7 TeV
WZ in $Wb\bar{b}$	30.7 ± 9.3 (stat.) ± 7.1 (syst.) ± 4.1 (theo.) ± 1.0 (lumi.)	22.3 ± 1.1	18.9 at 8 TeV
ZZ in $Zb\bar{b}$	6.5 ± 1.7 (stat.) ± 1.0 (syst.) ± 0.9 (theo.) ± 0.2 (lumi.)	7.7 ± 0.4	18.9 at 8 TeV

Table 1: Observed and expected cross-section.

3 Limits on Anomalous Triple Gauge Couplings (aTGC)

Many di-boson processes contain TGC vertices or are sensitive to aTGCs that are not allowed in the SM at tree level such as $ZZ\gamma$, ZZZ etc. The strategy for these analyzes is to consider all possible extensions to the SM Lagrangian that preserve gauge invariance and CP symmetry and set limits on possible enhancements of these terms. In general, enhanced TGCs should result in excess of events in the boson high P_T tails and at high mass. We therefore investigate these distributions to set limits. Analysis reviewed above gives limit on anomalous ZZZ and $ZZ\gamma$ couplings based on the invariant mass distribution of the four-lepton system at 8 TeV [1, 9]. The measured couplings are $-0.004 < f_4^{Z,\gamma} < 0.004$, and $-0.005 < f_5^{Z,\gamma} < 0.005$ at 95% CL, which are in good agreement with the SM predictions.

4 Summary

Figure 1 shows the relative production cross section for various electroweak boson pairs and Table 1 lists the values of the observed cross sections together with the expectation from the SM. The measured results are consistent with the SM predictions, within uncertainties. Also, no evidence for anomalous coupling in any of above processes are seen.

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